REMARKS

The rejections of Claims 1-9 and 11-13 as being unpatentable over Muller in view of Carawan and of Claims 14-21 as being unpatentable over Muller in view of Carawan and further in view of Kromrey, both under 35 U.S.C. §103(a), are respectfully traversed. Applicant requests reconsideration in view of the foregoing amendments to Claims 1 and 14, the previous comments regarding the cited prior art and the following remarks.

The Office Action asserts that the references "all address the common problem of composites that allow vapor and fluid flow" but does not substantiate that assertion by citation to the references themselves. Applicant previously invited the Office to point out where the common problem has been addressed, but thus far the record is silent.

It has been and still is the Applicant's position that the section 103(a) rejections are based upon impermissible hindsight evidenced by the combination of non-analogous prior art. Applicant previously pointed out that filters and breather sheets perform essentially different functions. The Office Action attempts to overcome this very apparent distinction by arguing that breathing occurs in a filter because it allows fluids to pass through it. The Office would be hard pressed to find a single example of a document describing a filter that also refers to breathing, particularly as a tortuous path is the focus of filtering action. And the Office does not address the converse, namely that breather sheets are

not considered as a mechanism for filtering out materials. Indeed, as the attached materials show, filtering in composites is often done by <u>bleeder</u> sheets, not breather sheets, in order to absorb resin from the laminate. Persons of ordinary skill know that breather sheets are there to maintain a breathing path not to filter.

Claims 1 and 14 now also contain the "incompressibility" feature of Claims 3 and 16, respectively. Even accepting the hypothetical combination of Muller's filtering material as the starting point as modified by Carawan's filter element as well as by Kromrey's method of using breather materials, the resultant would not include an incompressible mesh layer permitting of uniform thickness. The Office Action refers to Fig. 6 of Muller, where there are several layers of perforated material in which the fibers at the edges of the perforations are frayed. The Muller patent teaches that a material should be chosen so as to fray to a large extent on tearing, e.g. a material similar to blotting paper. Fraying of the material is needed to ensure that the filtering action is high.

Putting aside the issue of equivalence between filters and breather sheets, Applicant submits that, even in the filter art, one of ordinary skill would not have found it obvious to combine the teachings of Muller and Carawan, the latter involving metal meshes and screens and thus not susceptible to fraying. Such a combination would undo what Muller was attempting to achieve as noted above. Moreover, the hindsight combination still would not have produced an

incompressible structure because the protruding parts of the perforations would be deformable, and the assembled sheet would be compressible. The same would apply were the metal mesh suggested by Carawan to be substituted for the fibrous filtering material in Muller's Fig. 15 embodiment or even if all of the layers in Muller's Fig. 15 embodiment were to be replaced by metal meshes or screens. Assuming that it was well known that a metal mesh is incompressible across its plane, and the metal filter media of Fig. 6 of Carawan could have been used in Muller that, even if metal meshes and/or screens were employed, the assembled filter element would still have been easily compressible across the plane of the assembled element.

The Office Action thus had not set forth a *prima facie* case of obviousness. Accordingly, early and favorable action is earnestly solicited.

If there are any questions regarding this response or the application in general, a telephone call to the undersigned would be appreciated since this should expedite the prosecution of the application for all concerned.

If necessary to effect a timely response, this paper should be considered as a petition for an Extension of Time sufficient to effect a timely response, and

please charge any deficiency in fees or credit any overpayments to Deposit Account No. 05-1323 (Docket # 038665.55712US).

Respectfully submitted,

July 16, 2008

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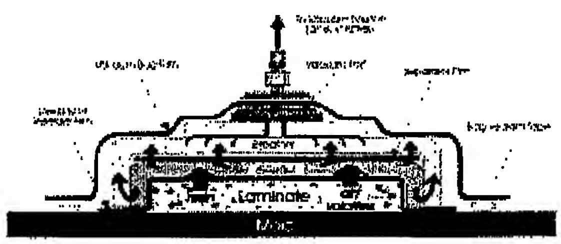
Guide To Composites

Vacuum Bagging

There are three main purposes for vacuum bagging:

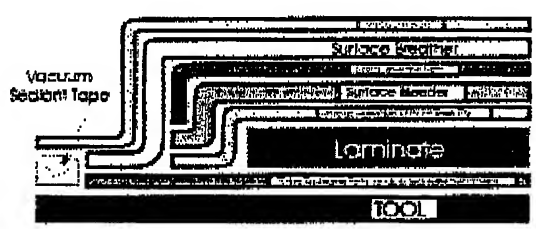
- Application of compaction pressure to consolidate plies
- Extraction of moisture, solvents, and volatiles from curing composite
- Allow resin to flow and be absorbed without hydraulic lock

The maximum compaction pressure available at sea level with a perfect vacuum bag is 14.7 psi (29.92 inches or 760 mm of mercury.) This maximum available pressure drops approximately 0.5 psi (1 inch or 25.4 mm of mercury) for each 1,000 foot gain in altitude. The routes for extraction of gases and resins is shown in the figure below:



The compaction pressure provided by a vacuum bag is crucial for good quality parts, when they are cured in a vacuum bag only. However, in an autoclave cure, much higher pressures are routinely available, up to several hundred psi for some types of solid laminates. However, the vacuum bag is still required in these circumstances, to extract the gases and reduce porosity.

How to sequence and use the variety of materials used in vacuum bagging can be one of the most confusing aspects in performing composite repair. The sequence of materials used is called the bagging schedule.



Release film or peel ply

The first layer that goes against the uncured laminate is a release film or a peel ply that is used as a barrier between the laminate and the subsequent bleeder or breather layers. This layer can be non-porous or

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porous material depending on whether or not resin bleed is necessary. Often a perforated release film is used for a controlled resin bleed. The diameter and the spacing of the holes can vary depending on the amount of resin flow desired. A porous peel ply is used when you do not wish to restrict the resin bleed and/or a peel ply surface texture is required. A non-porous peel ply (commonly known as FEP, fluorinated ethylene propylene, or Teflon®) is used when no resin bleed is required, but evacuation of the volatiles and solvents is desired. This layer usually extends beyond the edge of the layup and can be sealed and/or secured with flashbreaker (FB) tape as required.

Bleeder layer

The bleeder layer is used to absorb resin from the laminate either through a porous peel ply or a perforated release film as described above. The bleeder layer is usually a non-woven synthetic fiber material that comes in a variety of different thicknesses and/or weights that range from between 2 oz./yd2 to 20 oz./yd2. Multiple layers can also be utilized for heavy resin bleed requirements. This layer usually extends beyond the edge of the layup and is secured in place with FB tape as required.

Separator film layer

The separator layer is used between the bleeder layer and the subsequent breather layer to restrict or prevent resin flow. This is usually a solid or perforated release film that extends to the edge of the layup, but stops slightly inside the edge of the bleeder layer, to allow as gas path to the vacuum ports. Non-porous FEP can also be used as a separator layer.

Breather layer

The breather layer is used to maintain a "breather" path throughout the bag to the vacuum source, so that air and volatile can escape, and so continuous pressure can be applied to the laminate. Typically synthetic fiber materials and/or heavy fiberglass fabric is used for this purpose. The breather layer usually extends past the edges of the layup so that the edge-band makes contact with the bleeder ply around the separator film. The vacuum ports are connected to the breather layer either directly or with strips that run up into the pleats of the bag. It is especially important that adequate breather material be used in the autoclave at pressure.

Bag film and sealant tape

The bag film is used as the vacuum membrane that is sealed at the edges to either the mold surface or to itself if an envelope bag is used. A rubberized sealant tape or putty is used to provide the seal at the periphery. The bag film layer is generally much larger than the area being bagged as extra material is required to form pleats at all of the inside corners and about the periphery of the bag as required to prevent bridging. Bag films are made of Nylon®, Kapton®, or P.V.A. (polyvinyl alcohol) materials.

In addition to bagging schedules, there are other issues in vacuum bagging:

- Thermocouple quantity and placement
- Caul plates
- Heat blanket issues
- Heat sinks
- Extra adhesive layers
- Vacuum port quantity and placement
- Bagging "pleats"
- How much vacuum to draw

There are no quick and easy answers here. The bagging schedules used with wet layup repairs are affected by the ambient temperature as well as the pot life and amount of resin used. With prepreg repairs, the shelf life of the prepreg as well as its out-time "B-stage" affect the bagging

schedule. Also, older but still certified prepreg may require a different schedule than fresh prepreg. The best practice is to test first whenever in doubt.

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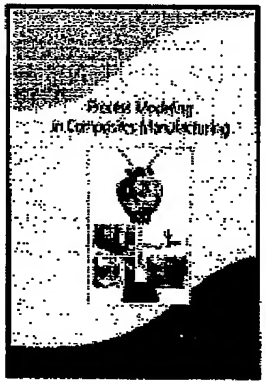
Process Modeling in Composites Manufacturing

By Suresh G. Advani, E. Murat Sozer



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By Suresh G. Advani, E . Murat Sozer

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CRC Press

Composite materials

456 pages

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An ideal introductory text, this book helps readers understand and improve current manufacturing processes as well as invent novel composite processing techniques. It includes qualitative questions and fill-in-the-blank exercises along with quantitative problems. The contents covers transport equations especially geared towards polymer flows, the basics of fluid mechanics and heat transfer principles, short fiber suspension and advanced thermoplastic manufacturing methods, reaction and crystallization kinetics and permeability of fabrics, conventional assumptions in polymer composite processing, and modeling tools such as dimensionless analysis and closed forms solutions.

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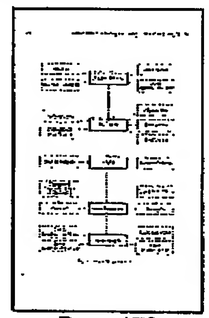

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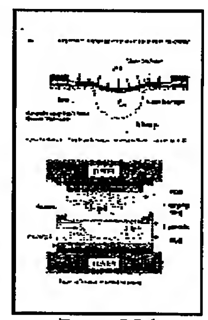

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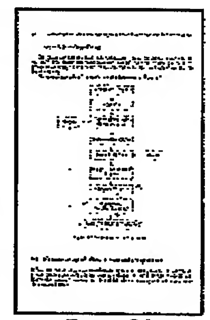

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However, in other industries where parts are small and not complex, the autoclave process can be cost effective. High volume production can be achieved by reducing cycle time by choosing materials that cure faster. Multiple parts could be cured simultaneously. One can address small curvatures and minor geometric complexities by placing the wet composite on a tool surface. As the resin heats up, the plies become less stiff and will adhere to the shape of the tool lying beneath it.

The advantages of the use of autoclaves include the ability to process a wide variety of materials and be able to obtain a very high fiber volume fraction in the composite due to its ability to apply high pressures. Hence, the autoclave has traditionally been used to process composite structures for the aerospace industry. The main disadvantages of the use of the autoclave are the high initial capital investment and the inability to use the pressure and temperature control effectively to produce void free composite structures. In addition, one cannot make complicated near net shaped structures as the mold is usually one sided. Also most of the cure cycles developed for aerospace structures are slow and can take hours before one can remove the part from the autoclave rendering it unsuitable for high volume production.

8.2.1 Part Preparation

The autoclave has been successfully used for many years to make composite parts which have no or negligible geometric complexity. Hence, the tool is usually a flat plate with very few curvatures and inserts. The tool material may be aluminum, steel, nickel, invar or even a composite depending on the application and the cost. A release film or a coating of release gel is usually applied on the tool surface for easy removal. The composite layup, consisting of prepregs or tapes, is placed on the tool surface sandwiched between release plies or fabrics. Cork or solid spacer plates are placed around the perimeter of the stacked plies, and they act as dams and limit resin flow in the lateral direction. The release film and release fabric are necessary for easy separation of the composite part from the tool surface and the vacuum bag. Bleeders are used to absorb excess resin in the thickness direction. The release fabric, in addition to assisting in releasing the composite from the tool, allows resin to flow into the bleeders. Peel plies provide surface texture and protect the part surface during handling. The breather material allows for uniform distribution of vacuum over the surface of the part. An inner vacuum bag is placed on top to seal the assembly along the tool surface and the perimeter dams. A caul plate covers the whole assembly. The role of the caul plate is to improve the surface finish of the part and improve dimensional tolerance by applying uniform pressure and minimizing ply movement. The caul plate may be semi-rigid and is made of thin metal, composite or rubber material or may be rigid for critical dimensional tolerance. The vacuum bag and breather material creates vacuum pressure inside the assembly. The driving force for consolidation is the difference between the autoclave pressure on the outside and the vacuum pressure inside the vacuum bag. A typical stacking order of layers is shown in Figure 8.3.

8.2.2 Material and Process Parameters

The goal of consolidation is to force air pockets (or voids) and excess resin out of the structure. By squeezing these flaws out of the composite part, a single coherent structure can be made by inducing intimate contact between the individual plies. The final structure will be thinner than the original material placed into the autoclave, but the fiber volume fraction, V_f, will increase making it a stronger part. Moreover, due to consolidation, the interlaminar shear strength will also increase.

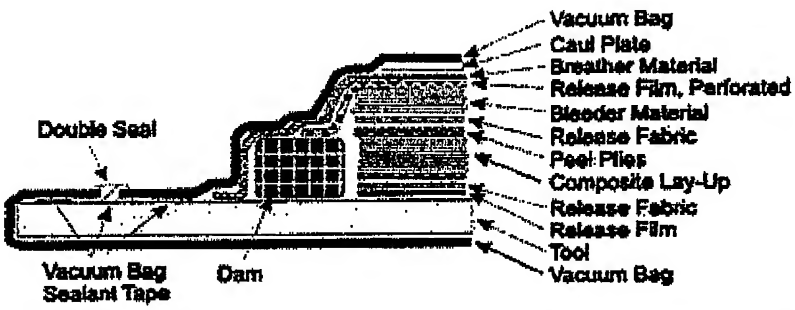
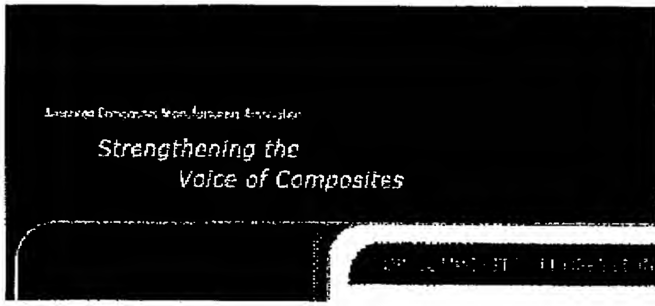


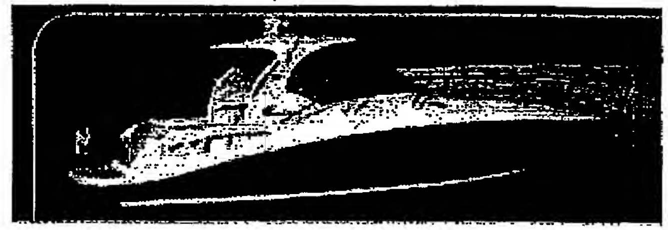
Figure 8.3: Schematic of stacking order in autoclave processing (redrawn from [297].)

Typically, thermosets have been used in autoclave processing. For most thermoset resins, the heat of the autoclave is actually necessary to initiate the cure reaction. The typical temperature range for autoclave processing of thermosets is around 100-200°C, with pressures in the 600-700 kPa range. Thermoplastics can also be used, but as is typical with thermoplastics, the temperature and pressure requirements are much higher than those for thermosets. For example, thermoplastic matrix materials such as PEI or PEKK require processing temperatures in the 300-400°C range with pressures of the order of 1 MPa.

The typical inputs to the autoclave process are the raw material quality, attributes of part preparation and handling, and most importantly from the process modeling viewpoint, the pressure and temperature cycle imposed on the autoclave for composite manufacturing. The quality of the part manufactured is measured in terms of final thickness or dimensions, degree of cure or cross-linking (for thermosets) and void or porosity content. The prepregs used in the composite layup can be either impregnated (either partially or fully) tapes with smooth surfaces, or fully impregnated tapes with rough surfaces. It was found that fully impregnated tapes with smooth surfaces do not provide a path for the volatiles and air to escape from the part and can lead to a lower quality part. The material preparation can influence the part quality if the procedure of layup is not executed in a repeatable fashion. However, as a process modeler, the most effective way to influence the part quality is by controlling the pressure and the temperature cycle during the curing and consolidation of the composite part.

An example of a pressure and cure cycle is shown in Figure 8.4. There are typically three stages of autoclave processing. Stage I is the heating stage. At the same time, the pressure is ramped up inside the autoclave during this stage. The first pressure ramp and hold in stage I is for the viscosity to go down and for excess resin to flow vertically into the bleeder material. The second ramp and hold is for polymerization of the resin to initiate during which time the viscosity rises dramatically. Stage I ends when the selected processing pressure and temperature are reached. Stage II is essentially a "hold" stage. The autoclave is maintained at the processing pressure and temperature to allow consolidation and curing to occur during this stage. As the cure reaction proceeds and generates heat due to polymerization, in stage III, the temperature is lowered to allow the excess heat from the reaction to diffuse through the part but the pressure is maintained to prevent voids from growing. When the cure reaction is complete and the temperature of the part is lowered, the pressure is released and the part is removed from the autoclave. The vacuum is discontinued to allow for out-gassing of volatiles. Although the autoclave pressure is high,





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Boy Scouts of America Composites Merit Badge - Overview of composite processes

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There are two general divisions of composites manufacturing processes: **open molding** and **closed molding**. With open molding, the gel coat and laminate are exposed to the atmosphere during the fabrication process. In closed molding, the composite is processed in a two-sided mold set, or within a vacuum bag. There are a variety of processing methods within the open and closed molding categories:

Open Molding

- Hand Lay-Up
- Spray-up
- Filament Winding

Closed Molding

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- Resin Transfer Molding (RTM)
- Vacuum Bag Molding
- Vacuum Infusion Processing
- Centrifugal Casting
- Continuous Lamination

Selecting which manufacturing process to select depends on a number of factors including cost, materials, size, and most important volume. Below is what processes would be used depending on production amounts:

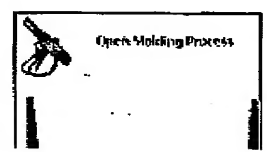
Low Volume Production

• Hand Lay-up
• Vacuum Bag Molding
• Vacuum Infusion Processing
Medium Volume Production
• Filament Winding
• Wet Lay-Up Compression Molding
• Resin Transfer Molding
• Centrifugal Casting

High Volume Production

- Compression Molding
- Pultrusion
- Reinforced Reaction Injection Molding
- Continuous Lamination

Open Molding

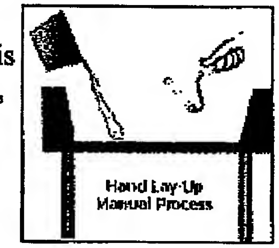


The heart of the open molding process is saturating fiber reinforcement with resin, then using

manual roll-out techniques to consolidate the laminate and remove entrapped air. A major factor in this operation is the transfer of resin from a drum or storage tank to the mold. The means used to transport the resin, in many cases, characterizes the specific process method.

Hand Lay-Up

Hand lay-up is an open molding method suitable for making a wide variety of composites products including: boats, tanks, bathware, housings, RV/truck/auto components, architectural products, and many other products ranging from very small to very large. Production volume per mold is low; however, it is feasible to produce substantial production quantities using multiple molds.



Process Description - Gel coat is first applied to the mold using a spray gun for a high-quality surface. When the gel coat has cured sufficiently, roll stock fiberglass reinforcement is manually placed on the mold. The laminating resin is applied by pouring, brushing, spraying, or using a paint roller. FRP rollers, paint rollers, or squeegees are used to consolidate the laminate, thoroughly wetting the reinforcement, and removing entrapped air. Subsequent layers of fiberglass reinforcement are added to build laminate thickness. Low density core materials, such as end-grain balsa, foam, and honeycomb, are commonly used to stiffen the laminate to produce sandwich construction.

Molds - Simple, single-cavity molds of fiberglass composites construction are generally used. Molds can range from very small to very large and are low cost in the spectrum of composites molds.

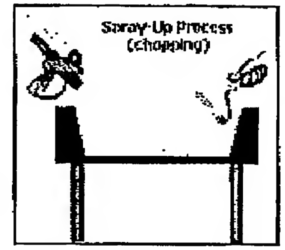
Major Advantages - Simplest method offering low-cost tooling, simple processing, and a wide range of part sizes. Design changes are readily made. There is a minimum investment in equipment. With skilled operators, good production rates and consistent quality are obtainable.

Spray-Up (Chopping)

Spray-up or chopping is an open mold method similar to hand lay-up in its suitability for making boats, tanks, transportation components and tub/shower units in a large variety of shapes and sizes. A chopped laminate has good conformability and is sometimes faster than hand lay-up in molding complex shapes. In the spray-up process the

operator controls thickness and consistency, therefore the process is more operator dependent than hand lay-up. Although production volume per mold is low, it is feasible to produce substantial production quantities using multiple molds.

Process Description - As with hand lay-up, gel coat is first applied to the mold prior to spray-up of the substrate laminate. Continuous strand glass roving and catalyzed resin are fed through a chopper gun, which deposits the resin-saturated "chop" on the mold. The laminate is then rolled to thoroughly saturate the glass strands and compact the chop. Additional layers of chop laminate are added as required for thickness. Roll stock reinforcements, such as woven roving or knitted fabrics, can be used in conjunction with the chopped laminates. Core materials of the same variety as used in hand lay-up are easily incorporated.



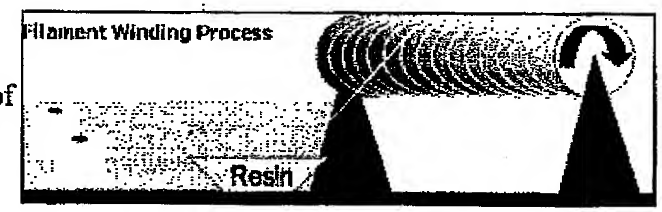
Molds - These are the same molds as in hand lay-up simple, single-cavity, molds of fiberglass composites construction. Molds can range from very small to very large and are low cost in the spectrum of composites molds.

Major Advantages - Simple, low-cost tooling, simple processing; portable equipment permits on-site fabrication; virtually no part size limitations. The process may be automated.

Filament Winding

Filament winding is an automated open molding process that uses a rotating mandrel as the mold. The male mold configuration produces a finished inner surface and a laminate surface on the outside diameter of the product. Filament winding results in a high degree of fiber loading, which provides high tensile strengths in the manufacture of hollow, generally cylindrical products such as chemical and fuel storage tanks, pipes, stacks, pressure vessels, and rocket motor cases.

Process Description - Continuous strand roving is fed through a resin bath and wound onto a rotating mandrel. The roving feed runs on a trolley that traverses the length of the mandrel. The filament is laid down in a predetermined geometric pattern to provide maximum strength in the directions required. When sufficient layers have been



applied, the laminate is cured on the mandrel. The molded part is then stripped from the mandrel. Equipment is available for filament winding on a continuous basis and two axis winding for pressure cylinders. Filament winding can be combined with the chopping process and is known as the hoop chop process.

Molds - Mandrels of suitable size and shape, made of steel or aluminum form the inner surface of the hollow part. Some mandrels are collapsible to facilitate part removal.

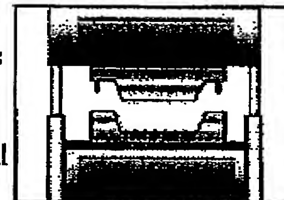
Major Advantages - The process makes the high strength-to-weight ratio laminates and provides a high degree of control over uniformity and fiber orientation. The filament winding process can be used to make structures which are highly engineered and meet strict tolerances. Because filament winding is automated, the labor factor for filament winding is lower than other open molding processes.

Closed Molding

Compression Molding

Compression molding is a high-volume, high-pressure method suitable for molding complex, fiberglass-reinforced plastic parts on a rapid cycle time. There are several types of compression molding including: sheet molding compound (SMC) which are, bulk molding compound (BMC), thick molding compound (TMC), and wet lay-up compression molding. Compression molding tooling consists of heated metal molds mounted in large presses.

Process Description - The mold set is mounted in a hydraulic or mechanical molding press. The molds are heated to 2500 to 4000 F. A weighed charge of molding compound is placed in the open mold. The two halves of the mold are closed and pressure is applied. Depending on thickness, size, and shape of the part, curing cycles range from less than a minute to about five minutes. The mold is opened and the finished part is removed. Typical parts include: automobile components, appliance housings and structural components, furniture, electrical components, and business machine housings and parts.



Compression Molding

Molds - Tooling is usually machined steel or cast alloy molds that can be in either single or multiple-cavity configurations. Steel molds are hardened and sometimes chrome plated for enhanced durability. The molds are heated using steam, hot oil, or electricity. Side cores, provisions for inserts, and other refinements are often employed. Mold materials include cast of forged steel, cast iron, and cast aluminum. Matched metal molds can cost fifty times as

much as an FRP open mold and tooling in the $50,000-$500,000 range is not uncommon.

Major Advantages - Compression molding produces fast molding cycles and high part uniformity. The process can be automated. Good part design flexibility and features such as inserts, ribs, bosses, and attachments can be molded in. Good surface finishes are obtainable, contributing to lower part finishing cost. Subsequent trimming and machining operations are minimized in compression molding. Labor costs are low.

Pultrusion

Pultrusion is a continuous process for the manufacture of products having a constant cross section, such as rod stock, structural shapes, beams, channels, pipe, tubing, fishing rods, and golf club shafts. Pultrusion produces profiles with extremely high fiber loading, thus pultruded products have high structural properties.

Pultrusion Process

Process Description - Continuous strand fiberglass roving, mat, cloth, or surfacing veil is impregnated in a resin bath, then pulled (pul-trusion) through a steel die, by a powerful tractor mechanism. The steel die consolidates the saturated reinforcement, sets the shape of the stock, and controls the fiber/resin ratio. The die is heated to rapidly cure the resin. Many creels (balls) of roving are positioned on a rack, and a complex series of tensioning devices and roving guides direct the roving into the die.

Molds - Hardened steel dies are machined and include a preform area to do the initial shaping of the resin-saturated roving. The dies include heating which can be electric or hot oil. The latest pultrusion technology uses direct injection dies, in which the resin is introduced inside the die, rather than through an external resin bath.

Major Advantages - The process is a continuous operation that can be readily automated. It is adaptable to both simple and complex cross-sectional shapes. Very high strengths are possible due to the fiber loading and labor costs are low.

Vacuum Bag Molding

The mechanical properties of open-mold laminates can be improved with vacuum bagging. By reducing the pressure inside the vacuum bag, external atmospheric pressure exerts force on the bag. The pressure on the laminate removes

entrapped air, excess resin, and compacts the laminate. A higher percentage of fiber reinforcement is the result. Additionally, vacuum bagging reduces styrene emissions. Vacuum bagging can be used with wet-lay laminates and prepreg advanced composites. In wet lay-up bagging the reinforcement is saturated using hand lay-up, then the vacuum bag is mounted on the mold and used to compact the laminate and remove air voids.

In the case of pre-impreg advanced composites molding, the prepreg material is laid-up on the mold, the vacuum bag is mounted and the mold is heated or the mold is placed in an autoclave that applies both heat and external pressure, adding to the force of atmospheric pressure. The prepreg-vacuum bag-autoclave method is most often used to create advanced composites used in aircraft and military products.

Process Description - In the simplest form of vacuum bagging, a flexible film (PVA, nylon, mylar, or polyethylene) is placed over the wet lay-up, the edges sealed, and a vacuum drawn. A more advanced form of vacuum bagging places a release film over the laminate, followed by a bleeder ply of fiberglass cloth, non-woven nylon, polyester cloth, or other material that absorbs excess resin from the laminate. A breather ply of a non-woven fabric is placed over the bleeder ply, and the vacuum bag is mounted over the entire assembly. Pulling a vacuum from within the bag uses atmospheric pressure to eliminate voids and force excess resin from the laminate. The addition of pressure further results in high fiber concentration and provides better adhesion between layers of sandwich construction. When laying non-contoured sheets of PVC foam or balsa into a female mold, vacuum bagging is the technique of choice to ensure proper secondary bonding of the core to the outer laminate.

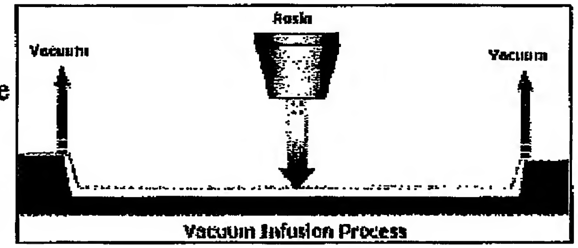
Molds - Molds are similar to those used for conventional open-mold processes.

Major Advantages - Vacuum bag processing can produce laminates with a uniform degree of consolidation, while at the same time removing entrapped air, thus reducing the finished void content. Structures fabricated with traditional hand lay-up techniques can become resin rich and vacuum bagging can eliminate the problem. Additionally, complete fiber wet-out can be accomplished if the process is done correctly. Improved core-bonding is also possible with vacuum bag processing.

Vacuum Infusion Processing

Vacuum infusion is a variation of vacuum bagging where the resin is introduced into the mold after the vacuum has pulled the bag down and compacted the laminate. The method is defined as having lower than atmospheric pressure

in the mold cavity. The reinforcement and core material are laid-up dry in the mold. This is done by hand and provides the opportunity to precisely position the reinforcement. When the resin is pulled into the mold the laminate is already compacted; therefore, there is no room for excess resin. Very high resin to glass ratios are possible with vacuum infusion and the mechanical properties of the laminate are superior. Vacuum infusion is suitable to mold very large structures and is considered a low volume molding process.



Vacuum Infusion Process

Process Description - The mold may be gel coated in the traditional fashion. After the gel coat cures, the dry reinforcement is positioned in the mold. This includes all the plies of the laminate and core material if required. A perforated release film is placed over the dry reinforcement. Next a flow media consisting of a coarse mesh or a "crinkle" ply is positioned, and perforated tubing is positioned as a manifold to distribute resin across the laminate. The vacuum bag is then positioned and sealed at the mold perimeter. A tube is connected between the vacuum bag and the resin container. A vacuum is applied to consolidate the laminate and the resin is pulled into the mold.

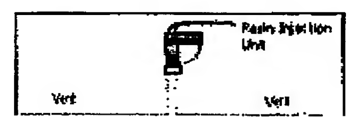
Molds - Molds are similar to those used for conventional open-mold processes.

Major Advantages - Vacuum infusion can produce laminates with a uniform degree of consolidation, producing high strength, lightweight structures. This process uses the same low cost tooling as open molding and requires minimal equipment. Very large structures can be fabricated using this method. Vacuum infusion offers a substantial emissions reduction compared to either open molding or wet lay-up vacuum bagging.

Resin Transfer Molding

Resin transfer molding is an intermediate volume molding process for producing composites. The RTM process is to inject resin under pressure into a mold cavity. RTM can use a wide variety of tooling, ranging from low cost composite molds to temperature controlled metal tooling. This process can be automated and is capable of producing rapid cycle times. Vacuum assist can be used to enhance resin flow in the mold cavity.

Process Description - The mold set is gel coated conventionally, if required. The



reinforcement (and core material) is positioned in the mold and the mold is closed and clamped. The resin is injected under pressure, using mix/meter injection equipment, and the part is cured in the mold. The reinforcement can be either a preform or pattern cut roll stock material. Preforms are reinforcement that is pre-formed in a separate process and can be quickly positioned in the mold. RTM can be done at room temperature; however, heated molds are required to achieve fast cycle times and product consistency. Clamping can be accomplished with perimeter clamping or press clamping.

Molds - RTM can utilize either "hard" or "soft" tooling, depending upon the expected duration of the run. Soft tooling would be either polyester or epoxy molds, while hard tooling may consist of cast machined aluminum, electroformed nickel shell, or machined steel molds. RTM can take advantage of the broadest range of tooling of any composites process. Tooling can range from very low cost to very high cost, long life molds.

Major Advantages - This closed molding process produces parts with two finished surfaces. By laying up reinforcement material dry inside the mold, any combination of materials and orientation can be used, including 3-D reinforcements. Part thickness is determined by the tool cavity. Fast cycle times can be achieved in temperature controlled tooling and the process can range from simple to highly automated.

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